DECISION-MAKERS FIELD CONFERENCE 2005

# MINING IN NEW MEXICO

## The Environment, Water, Economics, and Sustainable Development

L. Greer Price, Douglas Bland, Virginia T. McLemore, and James M. Barker, Editors

New Mexico Bureau of Geology and Mineral Resources
A Division of New Mexico Institute of Mining and Technology
2005

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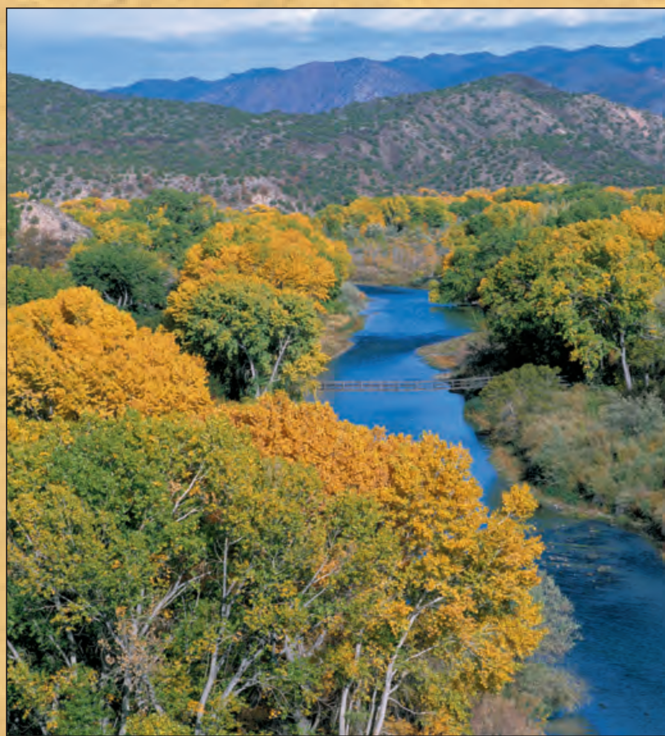
COVER PHOTO: Sangre de Cristo Mountains near Taos

# ENVIRONMENTAL AND WATER QUALITY ISSUES

DECISION-MAKERS
FIELD CONFERENCE 2005
Taos Region



# Acid Rock Drainage

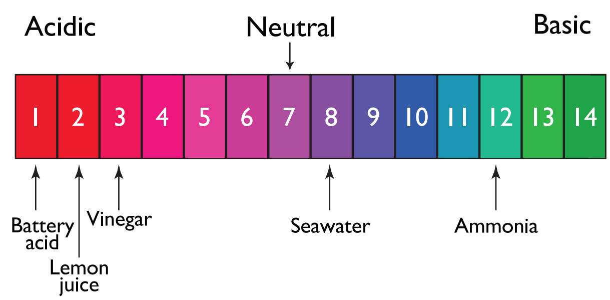
Kathleen S. Smith, *U.S. Geological Survey*

Acidic drainage is a common water quality problem associated with hard rock metal mining and coal mining. Acidic drainage (commonly called “acid rock drainage” or ARD) is formed when rocks containing sulfide minerals come into contact with water and oxygen to create sulfuric acid, which in turn releases metals (e.g., aluminum, manganese, copper, zinc, cadmium, arsenic, and lead) from the rocks. This acidic metal-laden water can negatively impact water supplies used by municipalities, agriculture, or wildlife. Understanding the formation of acidic drainage involves the fields of geology, chemistry, and biology. However, the fundamental source of acid and metals in the drainage is rocks, including the host rocks of a mineral deposit and waste rocks resulting from mining.

There are several phrases used to describe water affected by the weathering (wearing away or erosion and chemical decomposition) of rocks in mining and mineralized areas. The term "acid rock drainage" covers both mining related and naturally formed acidic drainage, and is used in this report to emphasize that not all drainage affected by the weathering of rocks is related to mining. The term "acid mine drainage” (AMD) is limited to drainage that is both acidic and mining related. The term "mining influenced waters" (MIW) is limited to drainage that is mining related, but not necessarily acidic. This term is useful because not all drainage from mining areas is acidic, but non-acidic drainage may still contain significant concentrations of metals.

### HOW DO YOU MEASURE ACID?

The pH scale is a measure of the amount of acid, with acids having pH values less than 7 and bases having pH values greater than 7. The pH scale is logarithmic, so water with a pH value of 3 is ten times more acidic than water with a pH of 4, and one hundred times more acidic than water with a pH of 5. Most natural waters are in the pH range of 5 to 9. Rain has a pH of approximately 5.7 because carbon dioxide from the air dissolves in raindrops to form a weak acid. Many familiar liquids also are acidic. For example, lemon juice and vinegar are both acidic and have pH values of approximately 2 and 3, respectively. Mining-influenced waters can have a wide range of pH values and are not always acidic. Young fish and some aquatic insects may be harmed by pH levels below 5. The pH also can affect aquatic life indirectly by changing other characteristics of water chemistry.




The pH scale, a measure of acidity, showing the pH of some common liquids.

### WHAT DOES MINING HAVE TO DO WITH ACID ROCK DRAINAGE?

One of the factors that has the greatest influence on the production of ARD is rock type. Rocks are made of minerals, naturally occurring chemical compounds that have specific crystal structures and documented chemical compositions. Different minerals have different properties and weather differently in the presence of water. For example, some minerals, such as halite (table salt), readily dissolve in water, whereas other minerals, such as quartz (found in beach sand), are practically inert (not subject to change). Various metals are contained within the structure of these minerals, and release of these metals into the environment depends on the properties of their resident minerals.

A mineral deposit is an accumulation of metals or minerals in a relatively small volume of the earth's crust. Mineral deposits form as a result of large-scale flow of metal-bearing fluids deep in the earth's crust. The processes involved in depositing the minerals are collectively called mineralization. When mineralized rock is mined, it exposes new surfaces that can be

Photo of the Carlisle mine in the Steeple Rock district of southwestern New Mexico. Geological characterization (below) can be very helpful in predicting potential environmental effects of mined sites.

| GEOLOGICAL CHARACTERISTIC | TYPE OF INFORMATION ACQUIRED |
|---|---|
| Geologic setting | pH buffering capacity<br>Ease of subsurface transport<br>Routes to biological receptors |
| Mineral deposit type | Which metals are present<br>Acid-generating capacity |
| Historical mine/mill activities | Predict contaminants of concern (e.g., mercury, cyanide)<br>Efficiency of sulfide removal from wastes |

Some aspects of geological characterization. Buffering minimizes pH changes in water when acid or base is added.

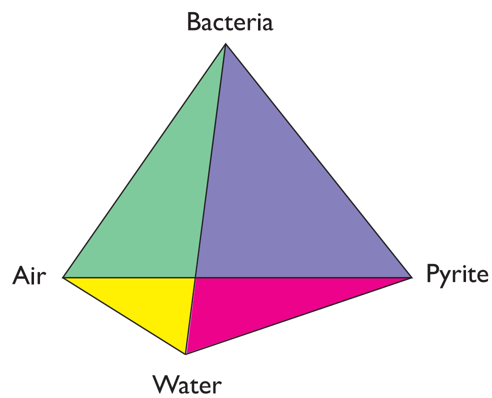
weathered and accelerates the production of ARD.

Mineral deposits can be categorized into different types, defined by characteristic minerals and associated potential environmental impacts. Some kinds of mineral deposits tend to produce very acidic, metal-laden waters, whereas others tend to produce less acidic waters with fewer or different dissolved metals. The particular metals and minerals present in rocks and waste rock are characteristic of how that mineral deposit was formed, and of the regional rock type, hydrology (how solutions move through the rocks), and geologic structures (such as faults). Geologic characterization can be very useful in predicting the potential environmental impact and footprint (impacted area) of a mined site.

Several characteristics of water that are common in drainage from mining and naturally mineralized areas include: low pH (acidic), elevated sulfate concentrations, elevated iron, aluminum, and/or manganese concentrations, elevated concentrations of other metals, and high turbidity, which is a measurement of the amount of small particles suspended in water. These components commonly depend on the mineralogy of the deposit.

### WHAT KINDS OF ROCKS MAKE ACID?

Sulfide minerals are common in many types of hard rock metal mining and coal deposits. Many sulfide minerals are relatively unstable under surface conditions, so when they are exposed to air and water they undergo the chemical reactions of weathering. Pyrite, or fool's gold (iron sulfide), is a common sulfide mineral that produces acid when it weathers. The generation of ARD begins with a startup reaction. For example, when pyrite comes into contact with water and oxygen (in air) the result is a reaction that produces dissolved iron and sulfuric acid (a mixture of sulfate and acid). In the acidic drainage generation cycle, once the startup reaction has begun, acid production is self-propagating as long as pyrite, water, and microorganisms (bacteria) are present. The acidic drainage generation cycle involves converting iron from one form (iron II) to another form (iron III). This conversion has been called the rate-determining step (the bottleneck) because it is slow at low pH. However, certain kinds of microorganisms can greatly speed up this conversion of iron by as much as 100 to 1,000,000 times, especially at low pH. Once the ARD reactions have begun, conditions are favorable for microorganisms to speed up the conversion of iron and lessen or eliminate the bottleneck in the acidic drainage generation cycle. This is important because iron III can readily react with pyrite (and some other sulfide minerals) and produce more acid. In fact, weathering via iron III can produce eight times more acid than weathering via oxygen (as in the startup reaction). So, the faster the iron can be converted from iron II to iron III, the more acid can be produced.




The Acid Rock Drainage (ARD) tetrahedron, showing the relationship between the four components that produce ARD. All four components are required to produce ARD.

## IS ACID THE ONLY PROBLEM?

The acid produced from pyrite weathering can attack other minerals in surrounding rocks. For example, acidic water can attack and dissolve common rock-forming minerals (e.g., mica and feldspar) and produce dissolved aluminum. Manganese and calcium also are common elements that have elevated concentrations in ARD.

In mined and mineralized areas it is common to see solid precipitates (residues) of various colors coating stream bottoms. These precipitates can result in high turbidity, which makes the water cloudy and interferes with sunlight penetration into the water (which in turn interferes with photosynthesis by aquatic plants). Iron forms coatings on stream bottoms over a broad range of pH conditions, and the coatings can vary in color from yellow, to orange, to deep red; these iron coatings are called *yellow boy*. The different colors are different iron-bearing minerals that form under different pH and chemical conditions; these minerals can be used as indicators of the chemical conditions present in the stream. Aluminum forms white coatings on stream bottoms above a pH of around 5. Precipitated aluminum may harm fish by accumulating on their gills. Manganese forms dark brown or black coatings at higher pHs, usually above 7. These various precipitates can form by natural processes in unmined areas, and their colors in stream bottoms were used as a prospecting tool by early miners to identify mineralized areas. Stream-bottom coatings may damage the habitat, inhibit growth, or kill aquatic organisms that live on the bottoms of streams.


The confluence of Deer Creek with the Upper Snake River near Montezuma, Colorado. As low-pH water containing dissolved aluminum mixes with higher-pH water, the aluminum precipitates to form a white coating on the streambed.

## WHERE DO METALS COME FROM IN ACID ROCK DRAINAGE?

Trace elements (e.g., copper, lead, zinc, cadmium, arsenic, selenium) are normally present in low concentrations in the earth's crust. However, in mineralized areas certain elements (depending on the deposit type) are present in above-average concentrations. Many of the trace metals in mineralized areas are found in various sulfide minerals. Minerals that contain trace metals can be weathered or attacked by acidic water or iron, thereby releasing metals into the environment. The concentration of a released metal is a function of (1) the concentration of that metal in the mineral, (2) the accessibility and susceptibility to weathering of the minerals that contain the metal, and (3) how easily the metal can be transported through the environment under the existing conditions.

Metals differ from organic contaminants in that they do not break down in nature. Therefore, once metals are released into the environment, they persist. However, metals may be affected by physical and chemical processes that can modify their transport through the environment. Once metals are released from their parent mineral, they can be transported by water or sediment, precipitated, or taken up by solid particles. Generally, metals are more easily transported in lower-pH waters (pH less than 4 or 5), which is why acidic drainage usually contains elevated concentrations of metals. However, some metals (e.g., zinc and cadmium) can be transported in near-neutral pH waters (pH 6 or 7), and some elements (e.g., arsenic, molybdenum, and selenium) can be transported under higher-pH conditions (pH greater than 7 or 8).

In mineralized areas and mining-related rocks, trace metals and acid may be temporarily stored in salts formed from evaporating mineralized solutions. Once wet conditions return, these salts can readily dissolve to release acid and metals. Dissolved metals also may be incorporated into solid particles; later changes in chemical conditions, such as pH, may cause the particles to release these metals back into the water.

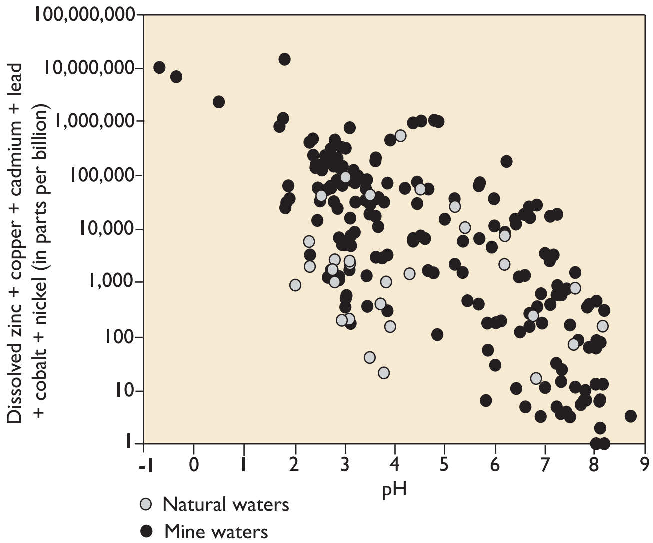



Diagram showing how the concentration of base metals (zinc, copper, cadmium, lead, cobalt, and nickel) vary with pH in natural and mine waters. Diagram courtesy of Geoffrey Plumlee and Sharon Diehl, U.S. Geological Survey.

## HOW DO YOU REMEDIATE ACIDIC WATERS?

Most mineral weathering reactions use up acid instead of making acid. Some minerals dissolve better than others or use up more acid when they dissolve. The mineral calcite (calcium carbonate), which is the mineral that makes up limestone, is very effective at neutralizing (counterbalancing) acidic solutions. This is because it dissolves fairly easily in acidic solutions and uses up acid when it dissolves. So, calcite commonly is used in the treatment of acidic waters. Moreover, it is a common mineral in some rocks and can neutralize acidic waters as they flow through those rocks. Other minerals also can help neutralize acidic solutions, but they tend to be less effective than calcite because they dissolve more slowly.

The final pH of the drainage from mining and mineralized areas is a balance between acid-generating reactions (e.g., pyrite weathering) and acid-neutralizing reactions (e.g., calcite weathering). The relative rates of these reactions and the accessibility of the reacting minerals ultimately determines the pH and metal content of the drainage water.

## WHAT TYPES OF MINING CAN PRODUCE ACID ROCK DRAINAGE?

Mineral deposits and the ores within them come in a variety of sizes and shapes. Therefore, methods used to mine a particular mineral deposit must be tailored to the size, shape, depth, and grade (richness) of the ore being mined. There are two main types of mining: surface mining and underground mining. In both, as minerals are removed, rock surfaces are exposed to water and air. This presents the opportunity for acid-producing pyrite weathering reactions to proceed and produce ARD. Therefore, openings from underground mines, such as adits, tunnels, and shafts, may drain ARD. Warning signs of ARD near mines include red-orange-yellow coatings on rocks, dead vegetation, and green slime growing in discharge waters. Even though not all discharges from mined areas are acidic, they may still contain significant concentrations of dissolved metals.

Compared to other industries, mining is unique in that it usually discards more than 90 percent of the material that is processed. Therefore, there is a lot of solid waste rock associated with mining, and the characteristics of this rock control its potential environmental impacts. Mining-related rocks from both underground and surface mining may produce ARD. Once fresh rock surfaces are exposed to water and air, the minerals in the rocks can weather. Historic mines generally did not have the technology to efficiently remove or isolate acid-producing minerals or metal-rich minerals from the mining-related rock. In addition, mine rock piles were commonly put in the most convenient place for the miners, generally close to the mining operation, which could be in or adjacent to a stream or drainage, or at the angle of repose on a mountainside. Therefore, many ARD water quality problems are associated with older mines.

## WHAT IS OPEN-PIT MINING, AND HOW DOES IT LEAD TO PIT LAKES?

Open-pit mining is a surface-mining technique that is used when the orebody is large and relatively near the surface. Open-pit mining involves repeated removal of layers of rock (both ore and overburden) to form a large open bowl-type structure. Several New Mexico copper and gold mines were mined by open-pit methods. Many open-pit mines exceed 1,000 feet in depth; therefore, most of the large open-pit mines extend well below the ground water table. Once mining and dewatering have ceased, these open-pit mines commonly fill with water to form pit lakes. At some point, pit lakes generally reach the point where the amount of inflow water approximately equals the amount of outflow water.

Pit lakes can receive inflow from both surface and ground water. Ground water models predict most pit lakes to be terminal basins, which means that they pull in water from all sides and evaporatively concentrate potential contaminants in the lake. During this evaporation process, water is evaporated and contaminants that were in the water remain behind; so, contaminant concentrations increase because there is less water present to dilute them. If this is the case, and there is no outflow from the pit lake (i.e., if it acts like a sump), then potential contaminants from the open-pit mine are contained within the lake. However, if there is outflow from the lake, potential contaminants may flow down gradient from the lake. Once a pit lake is filled, it may persist and fluctuate in elevation with seasonal changes in weather and water flow.

The New Mexico Mines Database includes a table listing thirteen current pit-lake areas in New Mexico. Some pit lakes have water quality that is suitable for recreation, such as the Copper Flat pit lake near Hillsboro, New Mexico. Other pit lakes have acidic waters with elevated metal concentrations, such as the Chino pit lake near Silver City, New Mexico. Many technical questions and issues remain about accurate prediction of the hydrology and water quality of future pit lakes.

### *Suggested Reading*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